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An Optically Pumped Polarized Ion Source for LAMPF

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Abstract

The status of the three operational optically pumped polarized H^- sources is reviewed. The optically pumped polarized H^- source development program at LAMPF is discussed. Aspects of this type of source requiring further research and development are discussed.

Introduction

The demand for polarized beam at LAMPF has steadily increased since the installation of the Lamb-shift source in 1977. In recent years, the need to satisfy a wider range of experiments has led to the consideration of upgrading to a more intense polarized H^- ion source. A feasibility study of the optically pumped polarized ion source began immediately after Anderson's article proposing that such a source was possible.[1]

In the concept proposed by Anderson, 5-keV incident protons capture spin-polarized electrons from an optically pumped polarized sodium vapor target. The relatively thick sodium-vapor target ($nl>10^{13}$ atoms/cm^2) is polarized by optically pumping with dye lasers tuned to the wavelength of the sodium D1 line. The capture of polarized electrons by the proton beam produces a polarized atomic hydrogen beam. The atomic hyperfine interaction is then used to transfer the atomic polarization to nuclear polarization through a diabatic field reversal technique known as a Sona transition.[2] Subsequent capture of a second electron in an unpolarized alkali-vapor target produces a polarized H^- beam.

Research efforts at LAMPF have made steady contributions to the optically pumped polarized ion source development. In 1981 we published theoretical estimates for the polarization transfer from the sodium atoms to the hydrogen beam as a function of magnetic-field strength.[3] Further, in that paper we proposed the use of an electron cyclotron resonance (ECR) source for the production of the incident proton beam to avoid the substantial emittance growth caused by charge-changing processes in a large magnetic field.[4] In 1982, we published the first measurements of optically pumping thick sodium-vapor targets without a buffer gas.[5] LAMPF has maintained involvement in the field through collaborations with the Japanese National Laboratory for High Energy Physics (KEK)[6-8] and TRIUMF.[9-11] In 1985, based on the results of Mori at KEK and Schmor at TRIUMF, a decision was made to begin construction of an optically pumped polarized ion source (OPPIS) at LAMPF.

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Optically Pumped Polarized Sources

The first operational optically pumped polarized ion source was constructed under the direction of Mori at KEK.[12] This system uses a 16.5-GHz ECR source and the polarized sodium-vapor target is in a 9-kG axial field. A flashlamp-pumped pulsed dye laser is used to optically pump the sodium target. The duty factor of this source is 70 μsec beam pulses at a repetition rate of 5 hz. This new pulsed laser system has produced 100% polarized sodium vapor targets of 6×10^{13} atoms/cm^2.[13] This source has produced H^- beams of 30 μA with a polarization of 60% and 180 μA with a polarization of 44%.

The optically pumped polarized ion source at TRIUMF is now being installed in their cyclotron injector. The acceleration of polarized H^- beams from the new source is planned for early 1988. The development of the optically pumped source at TRIUMF is complicated because the TRIUMF cyclotron requires dc operation and small emittance beams. Because of these requirements TRIUMF has performed significant development on ECR extraction optics[10] and on cw optical pumping techniques.[9] This source uses a 28-GHz ECR source and has a 12-kG charge-exchange field. A single broadband cw dye laser is used to optically pump the sodium vapor target. This source has produced 10 μA H^- beams with a polarization of 65% within an emittance of 0.04π cm mrad.[11]

The Institute for Nuclear Research at Moscow has a uniquely designed system. Instead of an ECR source, they produce the H^+ ions in a three-step process. A 5-keV H^+ ion beam is produced with a conventional duoplasmatron and then converted into an H^0 beam by charge exchange in hydrogen gas. The neutral hydrogen beam then enters the high magnetic field of the sodium target where it is reionized by electron stripping in a pulsed helium gas target. A flashlamp-pumped dye laser is used to optically pump the sodium target. The polarized electron capture occurs in a 15-kG magnetic field. The duty cycle of this source is presently limited by the use of a pulsed oil-cooled solenoid and the flashlamp-pumped dye laser to 20-30 μsec pulses at a repetition rate of 1 Hz. The source has produced 150 μA of H^- beam with polarization of 65% and 1 mA of H^+ beam with a polarization of 65%.[14]

OPPIS

The goal of the OPPIS development program at LAMPF is to achieve an operationally dependable source with 10 μA H^- beam and a polarization of 65%. The source must operate at a 10% duty factor with 800 μsec pulses and a repetition rate of 120Hz. A schematic diagram of the proposed optically pumped polarized H^- ion source for LAMPF is shown in Fig. 1. The source will use an 18 GHz ECR source. The extraction electrode system design is similar to the KEK and TRIUMF systems.[12] Since calculations[1] and recent measurements[11] show that higher magnetic fields produce higher beam polarizations, we have chosen to place the polarized sodium target in a 16 kG axial magnetic field. To avoid the large power requirements of a conventional magnet, a superconducting solenoid will be used. The superconducting solenoid is a persistent mode device with a 5" bore for design flexibility and increased vacuum pumping. To maximize the H beam polarization we plan to bias both the polarized sodium and

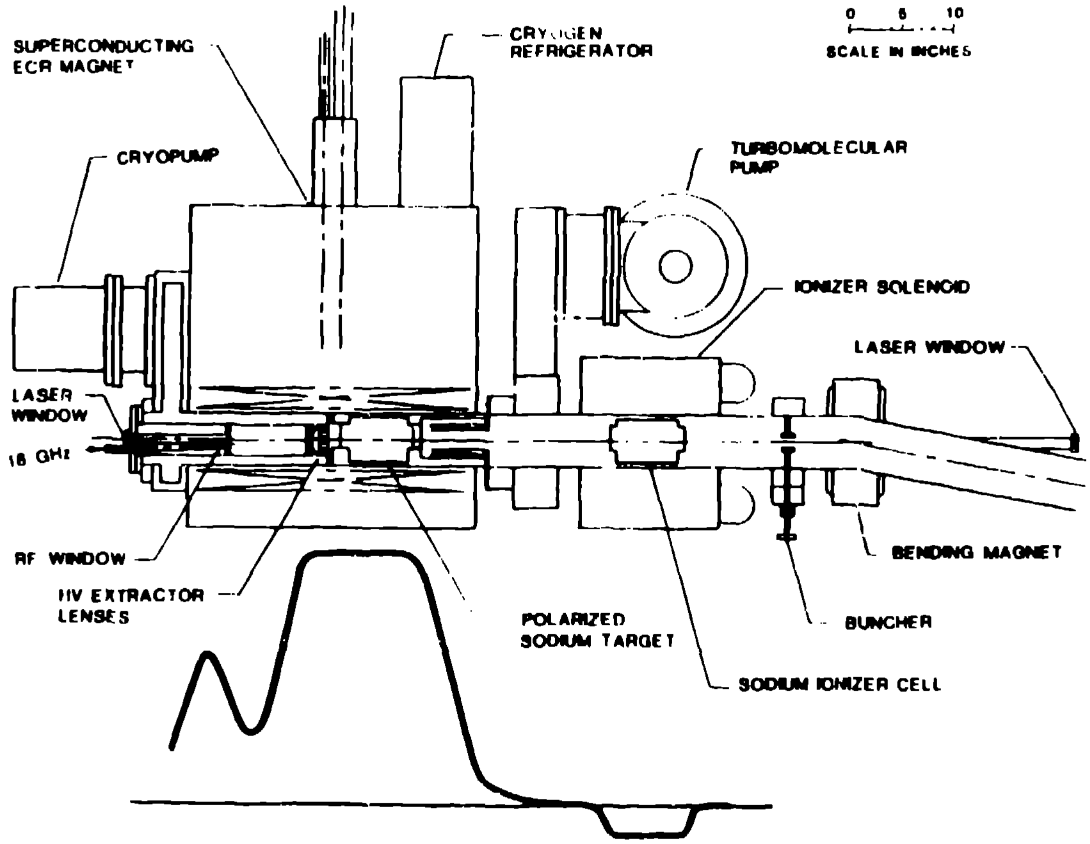

Fig. 1. Schematic drawing of the LAMPF optically pumped polarized source with the beam axis magnetic field profile shown below.

ionizer cells. This provides the polarized H^- ions with a unique energy. Thus, by energy analyzing the beam prior to injection into the 750-kV column, we can eliminate unpolarized background beam. Bending the polarized H^- beam also avoids dumping an intense neutral beam into the 750-kV accelerating column.

The sodium polarization at a particular target density depends on the amount of laser power within the Doppler-broadened sodium D1 absorption line and the depolarization rate of the sodium atoms. The use of a flashlamp-pumped dye laser in low-duty-factor sources allows the concentration of approximately 33 watts of peak laser power within the sodium absorption line.[13] Hence, flashlamp-pumped sources can reach high polarizations at near optimum sodium target densities. In high-duty-factor sources the polarized sodium target is the limiting factor. In order to improve the polarized sodium target for the LAMPF source, we have constructed the laser test facility shown schematically in Fig. 2. Using the Faraday rotation technique to measure the target polarization, we plan to test various non-depolarizing cell wall coating materials[15] and to compare the optical pumping efficiencies of the

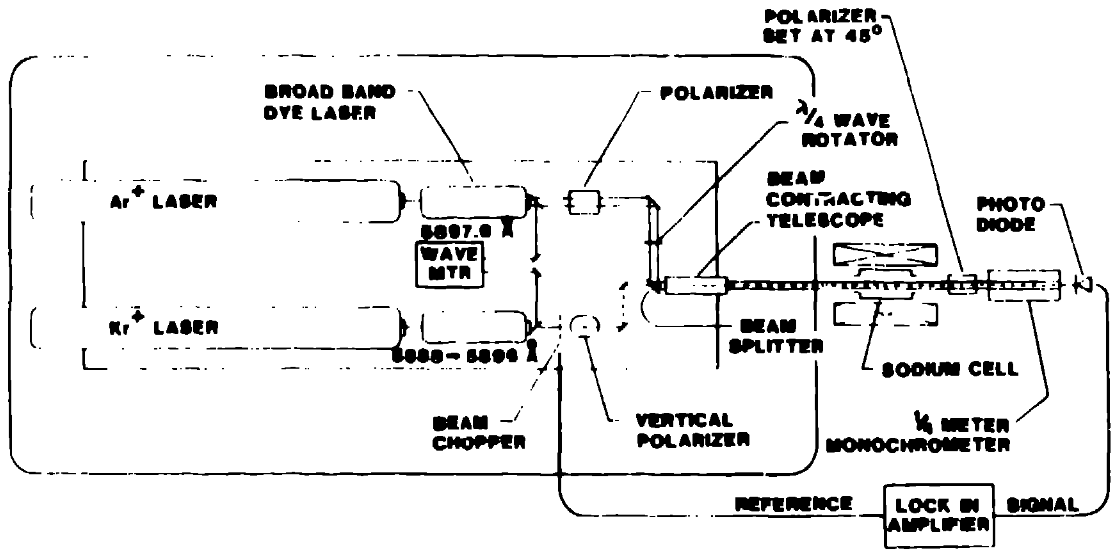

Fig. 2. Schematic diagram of the LAMPF laser laboratory.

Coherent CR-599 multimode dye laser with the Coherent CR-699 single mode laser. We plan to narrow the bandwidth of the multimode laser using an intra-cavity etalon similar to TRIUMF[9] and by using a mode-locking technique. Mode locking the multimode laser should narrow its bandwidth to approximately 8 GHz with little or no loss in average power. The mode-locked laser should produce 120-psec pulses at a repetition rate of about 160 MHz and a peak intensity of approximately 150 W. We also plan to try optically pumping a potassium target with the single-mode dye laser. Potassium has an absorption bandwidth of about 1 GHz which matches the single-mode laser bandwidth better than sodium. Calculations show that 1 W of single-mode laser power should produce a 92% polarized potassium target at a density of 5×10^{13} atoms/cm^2.

Conclusion

The performances of the existing optically pumped polarized ion sources after only 5 years of development is truly remarkable. However, there are still many aspects of this source that are not yet optimized. The collaboration between TRIUMF, KEK, and LAMPF has been and will continue to be highly productive. We plan to complete the OPPIS development project in fall of 1988.

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